

Simulation of a Magnetic Induction Method for Determining Passive Electrical Property Changes of Human Trunk Due to Vital Activities

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Abstract: Determining the changes in passive electrical properties of human tissues and the geometry changes of the body parts due to breathing and cardiac activity could be a method for monitoring these vital signs. We have designed a model with COMSOL Multiphysics to simulate a magnetic induction method for determining changes of these characteristics. Given the large number of parameters and variables, difficulties of anatomical modeling and various tissue properties, we are facing some numerical challenges. In addition, using magnetic induction method, we have to consider safety issues, standards and limitations.

We used COMSOL to simulate the induced currents in the human body and the resulting perturbation in the magnetic field for different tissue properties and geometries. As a result, we obtained the expected changes during breathing and we know the minimum distances and maximum excitation currents that could be used to meet the international safety standards.

Keywords: Magnetic Induction, Vital sign monitoring, Passive electrical properties, COMSOL

1. Introduction

The human body consists of many different types of tissues each with specific passive electrical properties (conductivity, permeability, and permittivity). Vital activities (like breathing or cardiac activity) lead to a characteristic change of these properties together with geometrical changes. Magnetic induction is a non-contact method which can be used to determine these changes and, as a result, to monitor these vital signs. The method is based on the creation of a primary magnetic field that will produce eddy currents in the trunk, these currents will produce a secondary magnetic field that has to be detected somewhere around the

trunk [1]. This measured signal is a function of the conductivity and geometry of the tissue and the geometry of the excitation and detection antennas. For a sample of material between an excitation coil and a sensing coil, and if the skin depth of the electromagnetic field in the material is larger than the dimension of the sample, then from [2]:

$$\Delta B/B \propto \omega(\omega\epsilon_0\epsilon_r - j\sigma)$$

Where ΔB is de secondary magnetic field, B is the primary field, σ is the conductivity of the sample, ϵ_r is its relative permittivity, ϵ_0 is the permittivity of free space, ω is the angular frequency of the excitation and $j = \sqrt{-1}$.

The objectives of this work is to evaluate, in the frequency range from 100 kHz to 10 MHz, the optimal positions of excitation and detection coils to obtain the maximum sensitivity of the method keeping the induced currents in the body under the international safety limits.

3. Modeling and Simulation

To simulate the method, a simplified anatomical 3D model of the human trunk (lungs and heart) was designed with COMSOL MULTYPHYSICS by using the Magnetic Fields interface. The main governing equations are:

$$B = \nabla \times A$$
$$(j\omega\sigma - \omega^2\epsilon_0\epsilon_r)A + \nabla \times H = J_e$$

Regarding the meshing limitations and sharp boundary problems, we tried to smoothening sharp corners in the design of the heart, lungs and surrounding tissues.

A current carrying coil (excitation coil) is located in front of the chest to generate the primary magnetic field.

Multiple parameters in trunk are changing while breathing, such as geometry and size of the lungs, dimensions of the chest and electrical

conductivity and permittivity of the lung tissue. In addition, since obtaining the convenient location of the coil regarding to the chest is of great interest especially for safety issues and compatibility with national and international standards, coil distance from the body was defined as a variable parameter. Parametric sweep has been used to cover all these parameter changes.

The values of the passive electrical properties for a frequency range of 100 kHz-10 MHz has been obtained from [3].

3.1 Geometry

The model consists of a sphere of 40 cm of radius, and inside this space, two cones for the lungs and a sphere as heart which has intersections with the lungs. In addition a cylinder is used to simulate the trunk. Two different view of the geometry is shown in Figures 1 and 2.

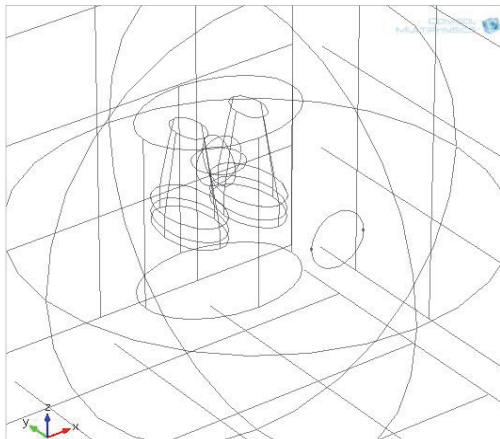


Figure 1. General view of the designed geometry of the trunk containing two lungs and a heart

The excitation coil is a parametric curve (Figure 3), 10 cm of radius, which is placed in a range of 5-20 cm from the chest by using the parametric sweep for the analysis. As a result, the coil is simulated as a 1 turn coil carrying a 1 A edge current. This current acts as an equivalent current source feeding the coil.

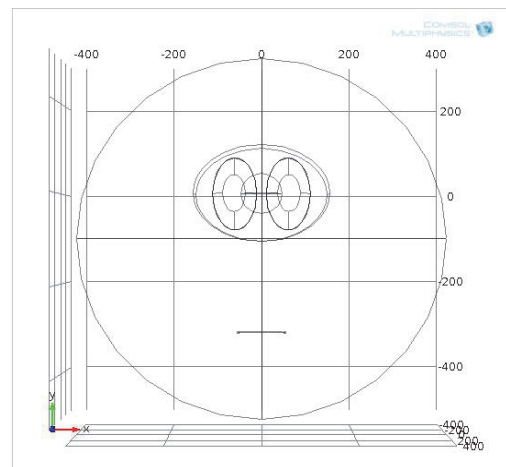


Figure 2. XY plane view of the model

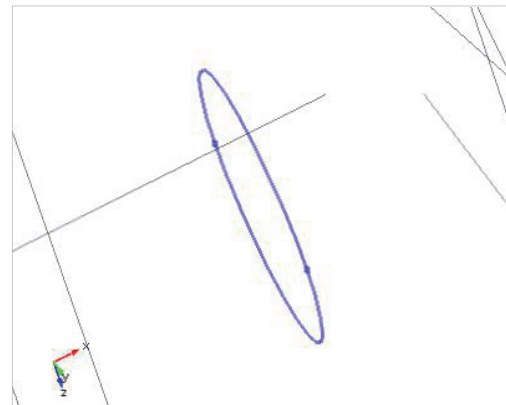


Figure 3. The parametric curve used as a 1 turn excitation coil

2. Results and Discussions

As stated before, the secondary signal which is the desired signal is proportional to the properties of the tissues and the geometry. As illustrated in Figure 4, the secondary magnetic field detected at the same plane where the excitation coil is located, increases as frequency rises. The dotted lines are the induced magnetic field values while the lungs are inflated. Since the conductivity of lungs is lower when inflated, the secondary magnetic field is lower.

In this figure, the secondary magnetic field is obtained at a distance of 5 cm from the chest, the same as the excitation coil. In further studies the secondary magnetic field will be obtained in other places to find out the best locations for the detection coil.

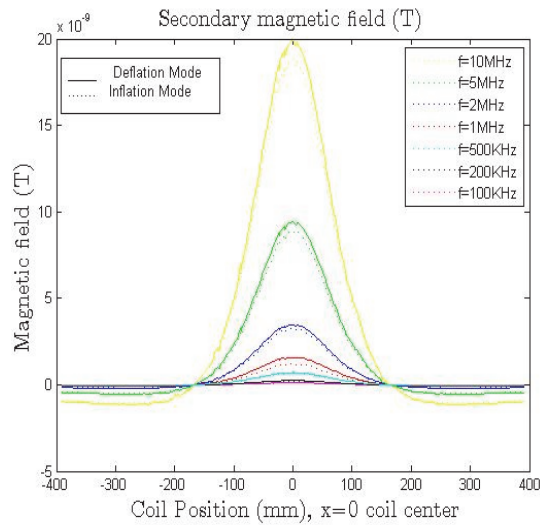


Figure 4. Secondary Magnetic Field for different frequencies and with the lungs inflated and deflated measured in the excitation coil plane.

Specific absorption rate (SAR) is a measure of the rate at which energy is absorbed by the body when exposed to a radio frequency (RF) electromagnetic field. The SAR value is calculated as

$$E_{SAR} = \sigma \frac{|E|^2}{\rho}$$

Where σ is the conductivity of the tissue, ρ is the density, and $|E|$ is the norm of the electric field. The most commonly used safety standards at present time are ANSI/IEEE C95.1 [4] and ICNIRP [5].

According to the ICNIRP basic restrictions for localized SAR, the maximum of absorption for head and trunk, is 2 (W/kg) and for the whole body is 0.08 (W/kg) [5].

COMSOL enable us to have a sensitivity analysis to find the best position for the coil in order to meet the requirements of the safety standards.

We calculated the absorption using COMSOL in the mentioned frequency range at different distances. In Figure 5, we show the SAR in the trunk when the excitation coil is located at the minimum distance from the chest, the frequency is the highest in the defined range (10 MHz) and the lungs are deflated. These conditions are the worst case giving the maximum SAR.

As expected, the SAR value is highest close to the surface of the body (Figure 5) and decreases when the distance between excitation coil and

the trunk increases (Figure 6). The SAR, as expected, increases with the frequency (Figure 6).

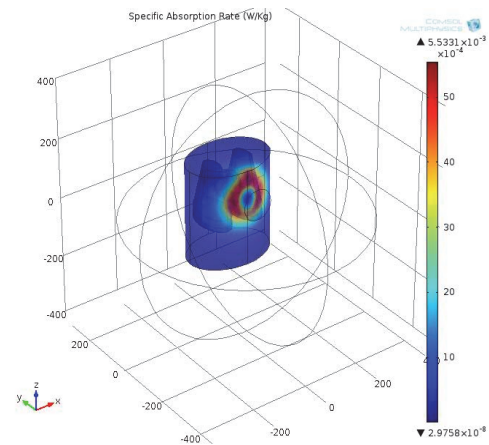


Figure 5. Specific Absorption Rate (worst case)

The results show that, even considering the worst case for exposing to the magnetic field, the maximum absorption rate is orders of magnitude less than the safety standard's limits. That is, for an excitation current of 1 A in a 1 turn coil at a distance of 5 cm from the chest at a frequency of 10 MHz we are still more than one order of magnitude under the safety limits imposed by ICNIRP standard.

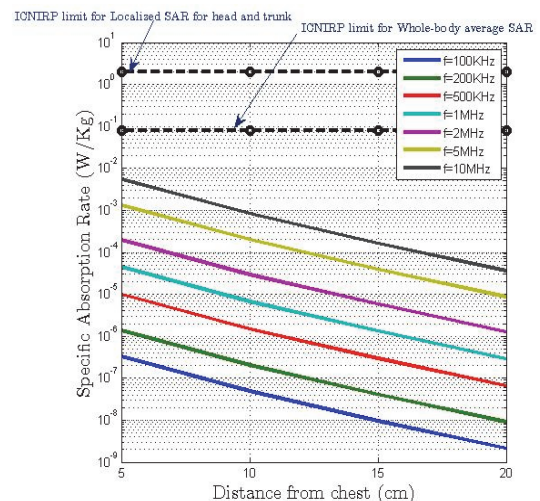


Figure 6. SAR vs. distance (100 kHz-10 MHz) for a current of 1 A in a 1 turn coil of XX cm of diameter.

The results displayed in figure 4 also show that the changes in the lungs due to breathing produced a noticeable change in the secondary magnetic field detected in the plane of the excitation coil.

3. Conclusions

By using the powerful interface and various features of the COMSOL, a model has been designed for simulating a magnetic induction method to monitor the changes of the electrical properties of human tissue produced by vital activities like breathing and heart beats. Results show that the changes in the passive electrical properties of the lungs during breathing produce a noticeable change in the secondary magnetic field detected in the excitation plane.

Apart from the results obtained for the secondary magnetic field produced by induced eddy currents, safety issues have been studied to fulfill the international standards for limiting exposure to magnetic fields.

4. References

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